Determining the Higgs Self Coupling at the LHC

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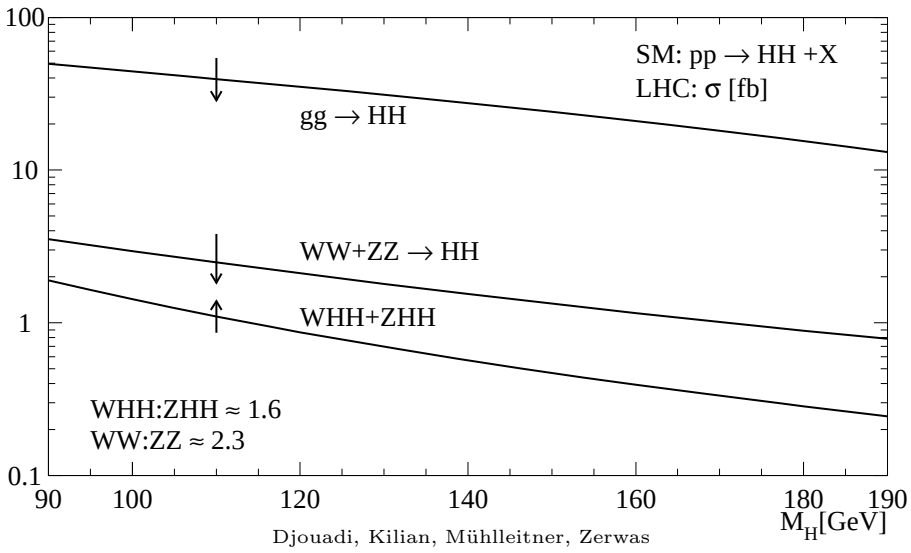
Higgs Bosons at the LHC

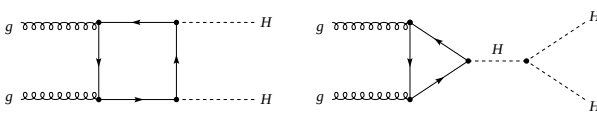
The Missing Piece

- multitude of observable channels in gluon and weak boson fusion
- measurement of Higgs mass $(H \to \tau\tau, \gamma\gamma)$
  measurement of couplings (minimize theory input)
  determination of Higgs coupling structure (possibly spin)
- Higgs potential: $V = -\lambda v^2(\Phi^\dagger\Phi) + \lambda(\Phi^\dagger\Phi)^2$
  relationship between mass and self coupling: $\lambda = m_H^2/(2v^2)$?

$\Rightarrow$ Higgs pair production



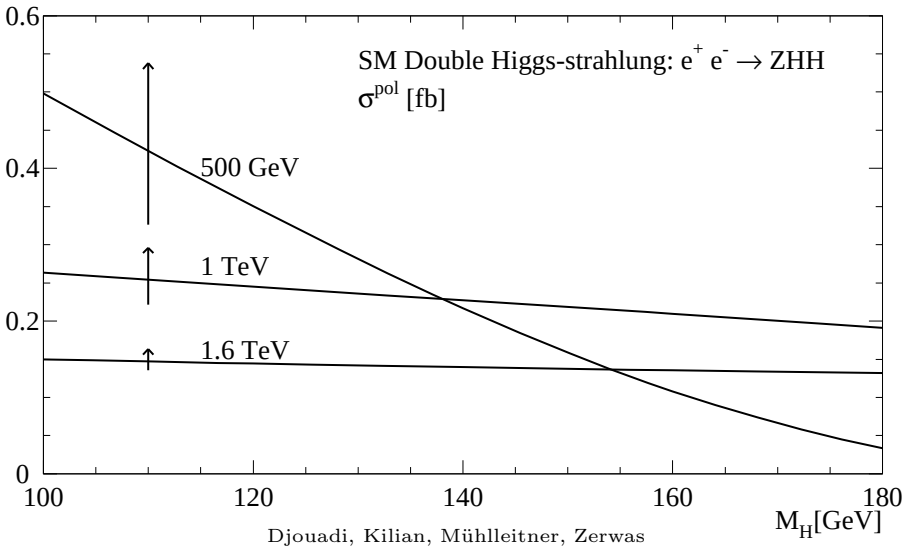
One-Loop Amplitude $gg \to HH$



- single off-shell Higgs production
- destructive interference with continuum graphs
- convenient effective theory $\mathcal{L}_{\text{eff}} \sim H^n G_{\mu\nu} G^{\mu\nu}$
  (links $ggHH$ vertex to gluon self energy for $m_H \ll m_t$)

What Do Others Say?

Rate at TESLA: $e^+e^- \to ZHH$



→ very limited number of events

→ low Higgs mass, decays $H \to b\bar{b}$ [Castanier, Gay, Lutz, Orloff]

→ S/B detector simulation, neural net analysis

m_h [GeV]	σ_{hhZ}(fb)	$\mathrm{N}^{500}_{\mathrm{hhZ}}$	ϵ_{hhZ}	$\Delta\sigma/\sigma$ $(\mathcal{L} = 500, 1000, 2000\mathrm{fb}^{-1})$		
120	0.186	93.	43%	24.1%	17.3%	11.6%
130	0.149	74.	43%	26.6%	19%	17.7%
140	0.115	57.	39%	32%	23%	17%

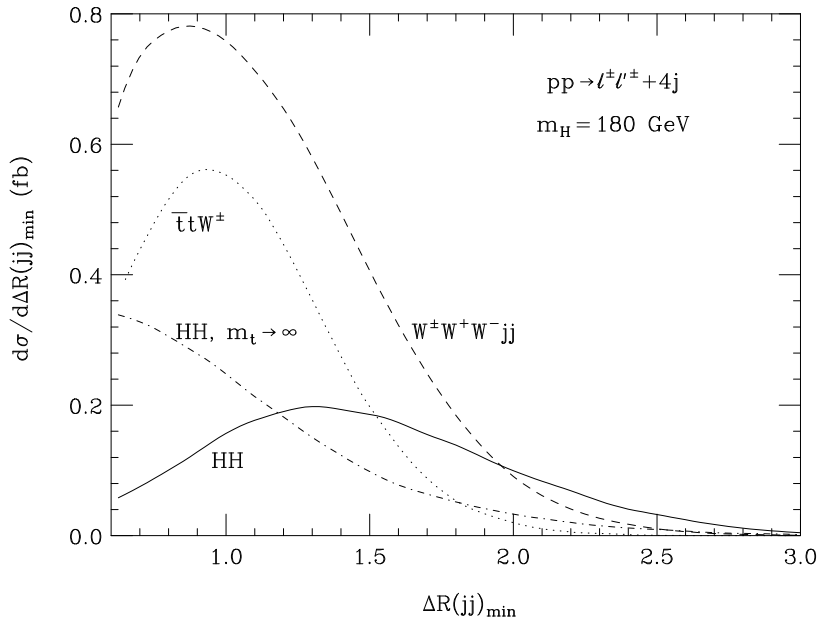
→ measurement of λ through total cross section ($m_h = 120$ GeV)

variable	$\Delta\lambda/\lambda$ $(\mathcal{L} = 500, 1000, 2000\mathrm{fb}^{-1})$		
$\mathcal{B}^{\mathrm{recoil}}$	42.2%	30.3%	20.3 %
NN output	35.7%	22.6%	18.0%

Higgs Pairs at the LHC

Signal Extraction

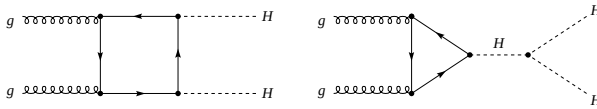
- signal $gg \to HH \to (W^+W^-)(W^+W^-) \to (jj\ell^\pm\nu)(jj\ell'^\pm\nu)$
  [Mangano et al.; Blondel, Clark, Mazzucato]
- dominant backgrounds: $WWWjj, t\bar{t}W$
  additional backgrounds: $WWZjj, t\bar{t}W, t\bar{t}Z, t\bar{t}j, WZ4j, WW4j, 4t$
  [$VV4j \equiv VV2j + 2j$, all others hard matrix element]
- parton level MC, one cut $\Delta R_{\rm jj,min} > 1$ only
- large top mass approximation completely useless



Signal & Backgrounds [fb]

m_h [GeV]	signal	N$^{2\times300}$	$WWWjj$	$t\bar{t}W$	$t\bar{t}Z$	$t\bar{t}j$	$WZ4j$	$WW4j$	$t\bar{t}t\bar{t}$
150	0.074	44	0.361	0.222	0.054	0.082	0.148	0.0052	0.0018
160	0.194	116	0.486						
180	0.177	106	0.404						
200	0.083	50	0.292						

Higgs Self Coupling

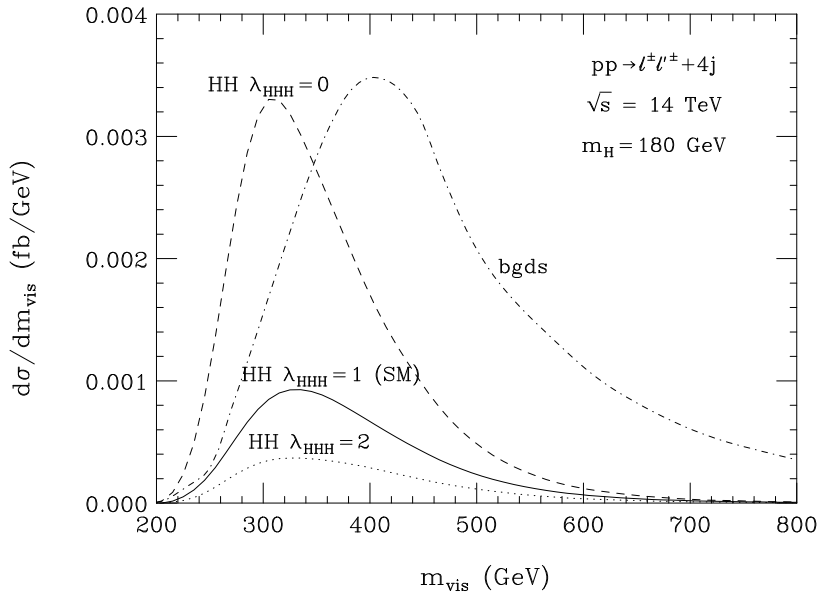


Statement about Higgs self coupling

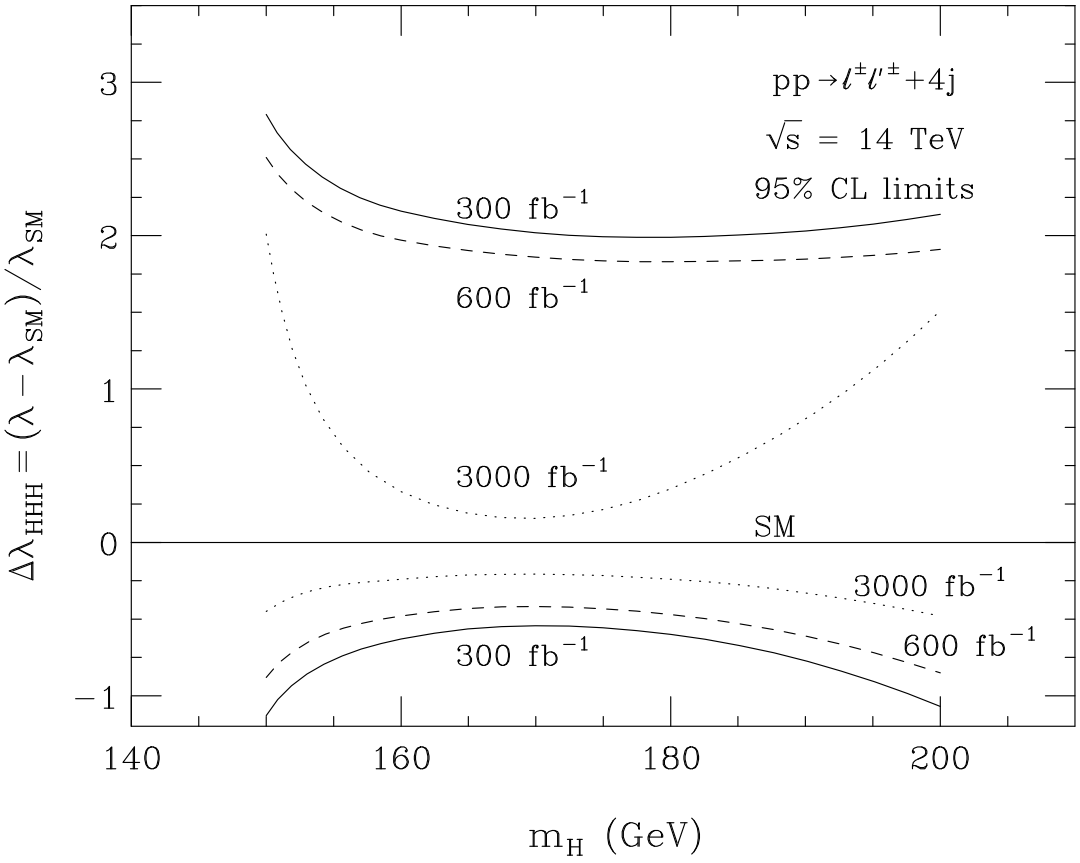
- certainly no 5σ signal for HH production (possible at vLHC)
- assumption: Standard Model Higgs type scalar
  derive limits on 'anomalous' Higgs self coupling
  exclude $\lambda = 0$ with enhanced rate (asymmetric limits)
- LHC: no extraction from total rate

Intermediate Higgs vs. Continuum

- useful distribution from visible mass $[(\Sigma_{j,\ell}\, p^\mu)^2]$
  (1) small for 2 particle final state (signal)
  (2) large for many particle final state (W, t in backgrounds)
- could be used for background suppression
  instead used to fit self coupling λ



Results



Issues worth to be resolved

- identification of jets from W decay vs. jet radiation
  (additional jet not always the softest jet)
- QCD and detector effects in visible mass
  (simple physics argument, PYTHIA jet approach valid?)
- background $t\bar{t}j$: dependent on $p_{T,\ell}$ cut
  (matrix element versus PYTHIA jet radiation?)
- $H \to 4b$ at LHC probably hopeless [Baur, TP, Rainwater (soon)]

HIGHER ORDERS

The Old Problem: NLO corrections known for signal only

Signal	Background
theoretical prediction $\Rightarrow$ major impact of NLO	measurement in side bins $\Rightarrow$ less impact of NLO
keep bulk of rate $\Rightarrow$ parton level useful	cut back into tails $\Rightarrow$ Monte Carlo needed
consistency: prediction of rate $\leftrightarrow$ topology PYTHIA jet radiation: approximate higher order topology $\Rightarrow$ normalization with best possible prediction for rate $\Rightarrow$ reduction of theoretical errors	
jet radiation, NLO rate $\Rightarrow$ reduced theoretical error	jet radiation, LO rate $\Rightarrow$ large theoretical error $\Rightarrow$ (1) impact of uncertainty? $\Rightarrow$ (2) impact of enhanced rate?
$pp \to HH$: fit to structure in signal, using NLO signal rate (1) allow for 30% uncertainty in background (2) allow for $K = 1.3$ in background (3) impact of side bin measurements	